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Uncontested minefields, ones without covering enemy fire, are cleared cautiously but still cause casualties. The Jug-Contained Fuel-Air Explosive (JUGFAE) concept does not send men into the minefield, but lets them proceed methodically from the minefield boundary. Safety and thoroughness are inherent in the setup process. The concept prescribes crane emplaced rows of plastic jugs containing detonable fuel. When fueled jugs are in place, a single large fuel-air explosion is triggered. The explosion will neutralize susceptible land mines. The "don't cross" line is moved across the neutralized area and the setup operation is repeated. The cycle repeats until the mined area is cleared. The errors in placing jugs and overlapping fuel-air clouds can be reduced so that a long line of clouds explodes. Based on 55 liters of fuel per jug, the needs are 92 jugs per km of front and a cost of about $1 per square meter. In very large minefields, jug numbers and costs are daunting. Increased cloud radius (6.2m presently) significantly reduces the needs.

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THE JUGFAE CONCEPT , by

JOHN D. SULLIVAN and
CHARLES N. KINGERY.

APRIL 1988

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U.S. ARMY LABORATORY COMMAND

BALLISTIC RESEARCH LABORATORY,
ABERDEEN PROVING GROUND, MARYLAND

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We are grateful to personnel of the Defence Research Establishment Suffield, particularly Ingar Moen, for work which tested the JUGFAE concept and provided data for the analysis. J. Richard Moore and Robert L. Umholtz of BRL corrected and clarified the statistical treatment of crane placement of jugs and helped analyze the exact area coverage of clouds.

PREFACE

This report expands on a paper given to the TTCP WTP-1 meeting chaired by Rodney T. Schmitke held at the Defence Research Establishment Suffield, Alberta, Canada, 13-14 March 1984. The problem of mine clearance in friendly areas was the subject of a brainstorming meeting conducted by Ray Thorkildson held at Aberdeen Proving Ground, Maryland, August 1983. Ideas put forth then were improved for the later meeting. The consensus became that the JUGFAE concept was the best choice out of current capabilities. The essential element of the concept, a plastic jug, appeared years before at Naval Weapons Center, China Lake, California, with Linden Perkins and others. A third meeting at DRES in July 1984 planned field trials to assess FAE's mineclearing capability and to demonstrate the JUGFAE concept. Those field trials took place at Suffield in Fall 1984.

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THE JUGFAE CONCEPT

1. INTRODUCTION

Jug-contained fuel-air explosive (JUGFAE) is a process for using fuel-air explosions for neutralizing land mines in areas that are not being contested. After a conflict, land mines can be cleared without danger from hostile fire but they still present inherent danger to the clearance party. This report describes how to proceed to clear large secure areas by a relatively safe method.

The prior art of clearing minefields after hostilities have ceased emphasizes detection. Mines are found one-by-one, as men cautiously probe the earth in their path or use metal or visual detection, and then either disarm the mine or detonate it in place.[1] The prior art is slow, incomplete and dangerous.

The new process precludes entering a minefield and allows the clearing operation to proceed from safe ground on the edge of the field, then move row-by-row forward into uncleared ground. The new process does not miss any ground as can easily happen with probes and sweeps. Also, after weathering and vegetation growth, mines cannot be visually detected. The new process does not involve looking for mines. The required fuel-air devices can be built quickly by moderately-skilled workers. The devices are fueled on-site and are not explosive until just before use, which makes handling a matter of normal fire precaution.

The major effort in minefield clearances in the past has been development of techniques to cross a defended minefield, the so-called assault breach. The entire emphasis is on speedily cutting a safe lane through the field. The process described in this report is not intended for use in that role and is not compared to those techniques.

This report is mostly an analysis to show the JUGFAE concept is valid in principle. There is enough technical detail of operations to convince readers that the concept is workable; but the report does not try to be rigorous in application technique. The practical details will be found by field experience.

2. GENERAL PROCEDURE

2.1 <u>Central Idea</u>. The central idea of the JUGFAE process is one detonation of simultaneously formed, overlapped fuel-air clouds to neutralize mines beneath the long cloud.

2.2 <u>Operations</u>. This process uses tested elements to form a practical method of neutralizing land mines in secure areas. It is the method of employment and not the essential element which is the emphasis of this report. The essential element is a research device in the public domain that is used for creating fuel-air explosions. It is a plastic jug holding a chemical liquid, e.g., propylene oxide, which is explosively disseminated in air, forming an aerosol cloud of fuel in air. The aerosol is, a short selected time later, detonated by a separate, small explosive charge pre-emplaced to be within the cloud. By itself, at any size, the jug gives too small a cloud to be useful for the said purpose of this process.

To form a novel and practical process for clearing land mines, the jug is multiplied, hung, wired, and spaced according to this report. The process is depicted in Figure 1. A crane puts the jugs in a row, parallel and inside the edge of the minefield. The jugs are spaced so that an individual cloud will partly overlap its neighbors' cloud. An armed charge is emplaced by the crane at the end of the row. The explosion of the charge will create a detonation wave that will carry through the whole long cloud. The detonation wave creates an overpressure on the ground that can set off or render inoperative many types of land mines. The dimensions of the cleared ground are visually evident. One part of the practicality of the process is that simultaneous detonation saves the time involved in proceeding singly. That time is in hooking up firing lines, withdrawing, firing, returning and inspecting, and repeating. The time saved by the process can be estimated. In an actual day, four instrumented fuel-air tests were separately conducted at BRL. Likely five could have been accommodated in an 8-hour day. However, with the process, it is supposed that five jugs could be laid out and fired in two hours. That makes 20 jugs a BRL day, a process gain of four times.

The procedure is now outlined. Commercial plastic jugs are scored with a hot soldering iron in order that the wall will break in a controlled fashion. Jugs are filled with propylene oxide and recapped. At the site the cap is exchanged for one holding a central burster tube. The tube is permanently sealed at bottom and contains plastic, stick, or cord explosive up to the neck of the jug and a blasting cap. The fuel to burster weight is most often made 100 to 1. The blasting cap wires come out of the tube through a putty-like duct packing which seals the top of the burster tube. The seal holds back the hot detonation gases which would burn the forming fuel-air cloud. Once the jug caps are exchanged, the explosive handler splices a long length of twisted pair to the blasting cap wires and to the disposable section, also twisted pair, of the electric firing line. The spliced section gives enough slack to permit the jug to be swung a good distance into the minefield. The jug firing line leads back to a grounded, locked transfer box. A heavy fixed electric cord leads from the box to the power supply in the firing trailer.

The jug is next put into a stand which will hold it at a height-of-burst such that the bottom of the cloud will brush the ground. For this to occur, the bottom of the jug is favorably 1.0 m above the ground. Fuel loss into the ground is minimized and highest impulse on the mines is thus obtained. A suitable stand is a larger copy of the wire tripod that is used by florists to hold funeral wreaths. The neck of the jug is wired to the top of the tripod, causing the jug to dangle erect inside the framework regardless of the ground unevenness. A modification at the top of the stand, such as an S-hook or a bar across two legs, will allow a crane hook to lift the jug out onto the minefield and let the hook slip out when the stand is put down. The next jug is prepared and it is lifted out. The spacing between jugs should be 0.88 of the expected diameter of a cloud to ensure cloud overlap. The overlap is needed as the detonation wave cannot proceed through plain air.

The jug size should be the largest commercially available, 55 liters. Filled it is 50 kg or the most that one husky man can hang in the stand. The slight mass means that the crane needs nil loading capacity. What it should have is rough terrain capability and a long boom. The boom reach must be at least cloud radius R for laying one row, 3R for two rows, 5R for three rows.

When the planned number of jugs is out, the cloud detonator is put out. Composition C-4 (1/4 lb) is suitable because it easily molds around the blasting cap and it can be taped to a wreath stand and swung out to the end of the jug line at about 1/2 radius of the cloud. The C-4's blasting cap is connected to a separate firing line, whereas all jugs are in parallel on their own firing line.

The crane backs off and people withdraw a safe distance or take cover in a portable, sound deadened bombproof. The firing is done using a sequence timer to switch voltage to the jugs and then the C-4 detonator. A delay of 100-150 ms will give a large, still-detonable cloud. A video tape recorder and television camera looking broadside to the cloud line should view the firing to verify that the detonation and not a burn has taken place. The difference is easily heard. Also inspection of the ground will give quick recognition of the results.

2.3 Cost

The cost of one large jug is broken down as:

Jug:	Large Jug	$30	
	Fuel (55 liters)	69	
	Burster Tube	1	
	Detonator	2	
	Det Cord	1	
	Stand	6	
		$109	$109
Cloud Detonators:	C-4, Detonator, & Stand		14
Labor:	Burster Ass'y (10/day @ $10/hr)		8
	Jug Score (30/day @ $10/hr)		3
			$134

Fixed Costs:

Crane, Low Capacity, Double Telescoping Boom	$60K
Firing Line	1K
Sequence Timer	2K
Power Supply	1K
TV Camera & Recorder	3K
Trailer	10K
Generator, 8 kW	2K
	$79K

Clearance Party: See end 5.4.

Project Officer	
Project Engineer	
Crane Man	
Loader	
Mechanic	
Utility Man	
(Ea @ $60K/Man-Year)	$360K

2.4 Examples of Successful and Unsuccessful Solutions to the Problem. This process will succeed in neutralizing land mines that are susceptible to fuel-air explosives. These are particularly single-impulse fuzed mines, which are actuated by the explosion's pressure/impulse, but also include other-influence fuzes which are rendered inoperative by the explosion. Certain fuzes, such as anti-tank shear pin types and anti-tank long impulse types are not FAE susceptible. Fuzed antipersonnel mines are much more susceptible to FAE than the corresponding anti-tank fuze, because they actuate at much lower pressure. Scatterable mines are believed to be non-susceptible. Whatever their resistance to FAE may be is moot in the process's application, because scatterable mines are designed to self-destruct a day or so after deployment. The use of the process will largely neutralize an area and will make a mine encounter rare enough that a finishing cleanup by some other means, outside the scope of this process, is then feasible. Since hitting a mine would be much rarer than before the FAE, the machinery will have a much greater time-between-failure. It may be efficient to make the next fuel-air shot at the end of the line or on the row behind, and create more ground for the proof means. The appropriate proof means will be suggested by intelligence of what mine types were laid. Colonel John Hill, Royal Engineers, speaking at DRES, 13 March 1984, stated that FAE would be useful even if it could not clear every kind of mine. It would be sufficient to clear less than all threats as long as the remaining threat was known, especially if the proof means was parties on foot. Colonel Hill wanted the FAE to neutralize any or all of three levels of threats:

- All trip wires and booby traps neutralized.
- In addition, all antipersonnel mines neutralized.
- In addition, all anti-tank mines neutralized.

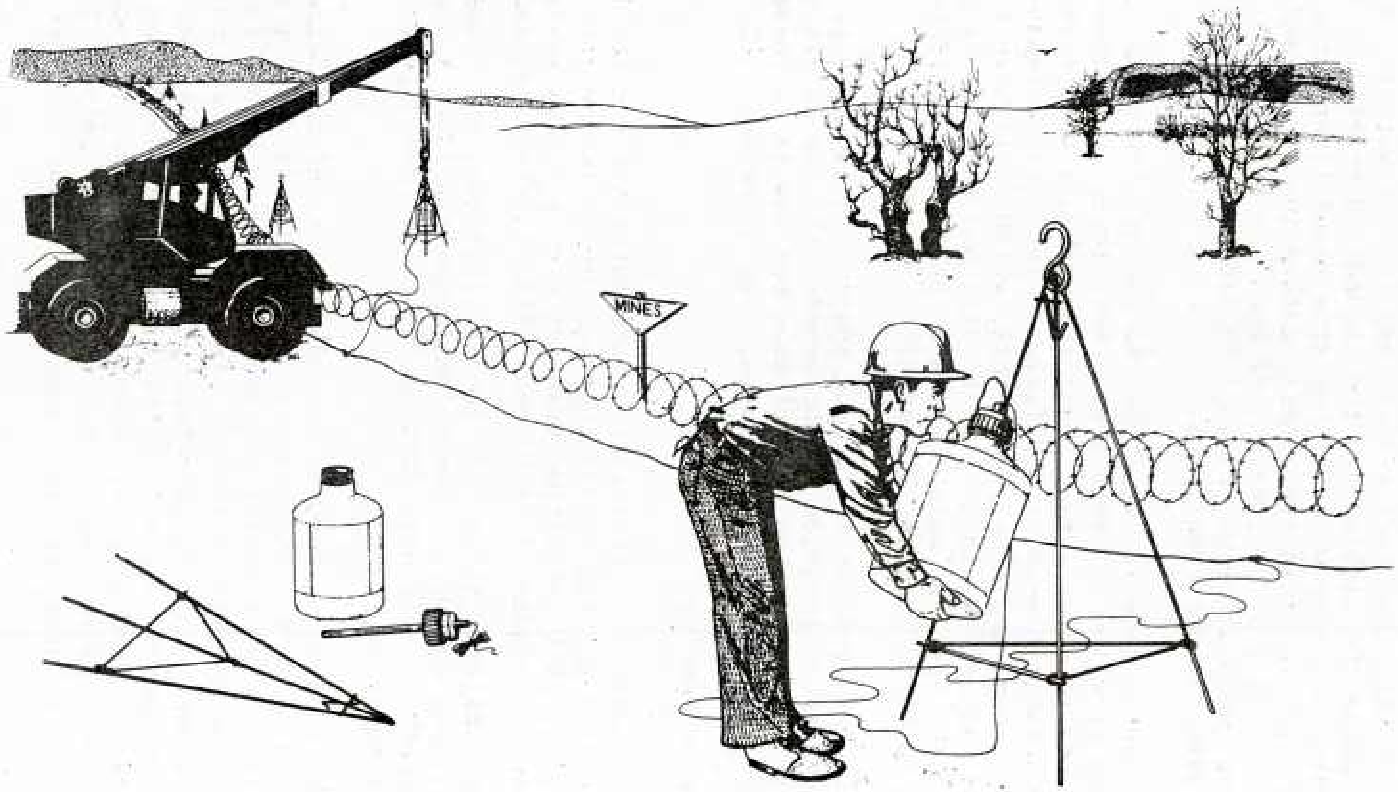

FIGURE 1. Laying in a line of jugs.

The process success is not especially weather or terrain dependent, as long as the crane can move. Arduous conditions will slow the setup time of a row of jugs. But conditions like wind or cold will not topple the jugs or cause a non-detonation. Marshy, puddled, slushy, brushy, or stony ground will not hurt the shock effect, and in fact wetness, but not snow, will better couple the airblast to the ground. However, the beneficial effect of adding standing water either from rainfall or water trucks may be slight. The depth to cause sympathetic detonation in a standard pattern minefield is one to two feet, or deeper than can be created. Dead or dry, but not living, vegetation may catch fire from an FAE. Minefield clearing may need to wait for wet conditions.

An unsuccessful solution would be the use of either FAE bombs or warheads taken from the SLUFAE system. Both bombs and warheads are too expensive to use to clear large areas; the warheads were intended to blow a lane for the assault breach of minefields. Both have accessories such as safe and arm system, and cloud detonators, which would have to come off. The bombs and warheads would have to be stripped down to the simplicity of the plastic jug. Also the metal shards of the casing would have to be picked up to make the land useful again.

Partial failure results if the jug spacing is too wide to give cloud overlap because the detonation cannot proceed through an air gap. If the jug spacing is too close, the area cleared per row is decreased. Both of these problems are solved in paragraphs 4 and 5, respectively.

3. PROOF OF CONCEPT

Proof-of-concept is a test that demonstrates the central idea. In JUGFAE, interested parties agreed that a four-jug inline shot would test the central idea: that detonation transfer across clouds would take place. The proof test was conducted in October 1984 at Defence Research Establishment Suffield, Alberta.[2] The 55-liter jugs and cloud initiator were hand emplaced on posts. Remote emplacement (crane) is not central to proof-of-concept. In a single day, two tests of four jugs inline were made and both were successful.

Aerial photography showed the clouds' growth and detonation transfer. The overlap was different than expected. The clouds did not merge into each other like the overlapping circles we draw but rather they heaped up where they touched. DRES personnel point out that the expanding clouds are opposed mass flows. Another phenomenon they observed is that the detonation wave seemed to stall at the merged region and then resume travel through the cloud. The wave motion was jerky instead of constant. A speed change is expected in regions of different fuel-air ratio. Their observations and remarks were made soon after seeing the test films.

In the following sections the analysis idealizes cloud overlap as a smooth, non-interacting superposition of circles, as in Figure 2.

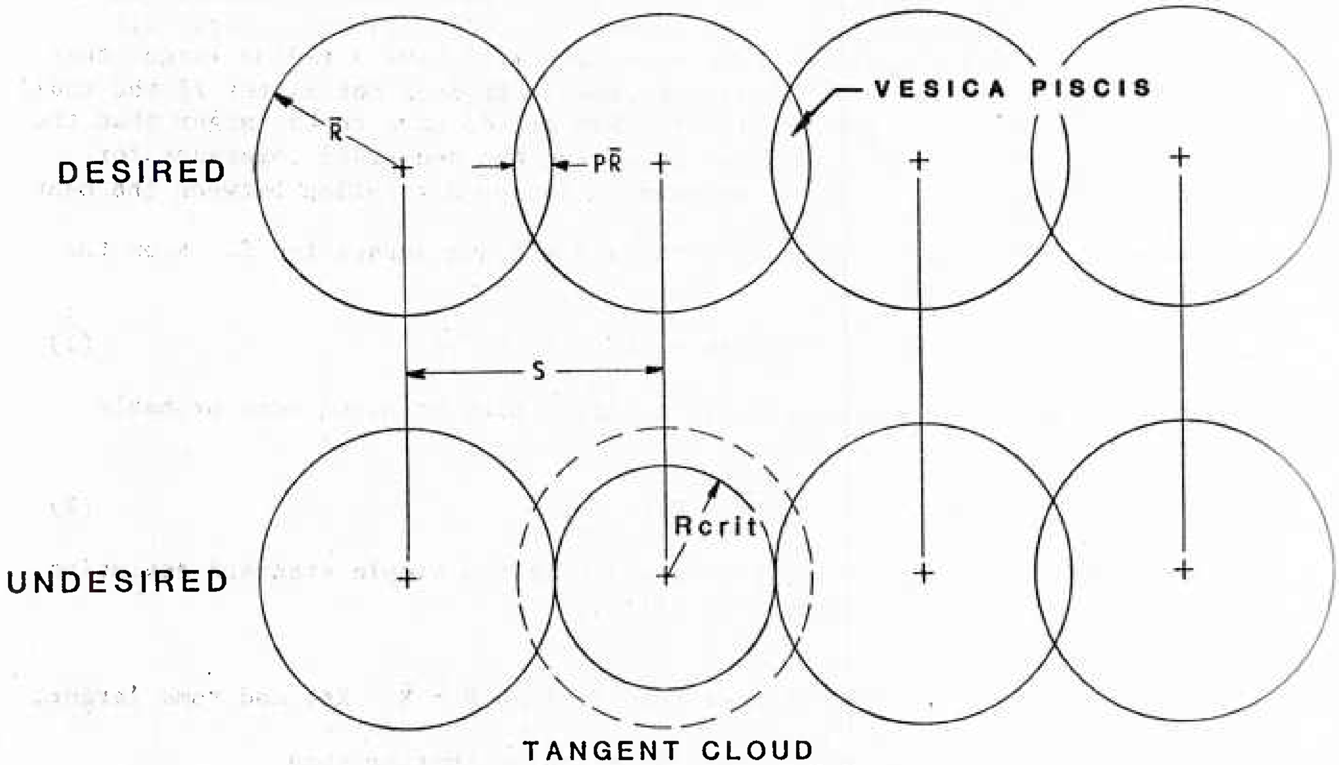

FIGURE 2. Tangent cloud.

For historical interest, the proper name of the intersection shape is the "vesica piscis," fish bladder. The shape is used in architecture, advertising, and Christian art.

4. LIKELIHOOD OF SUCCESS

4.1 Perfect Placement of Jugs. Partial failure results if the jug spacing is too wide for clouds to overlap. Part 4 finds the chance of non-overlap of the clouds. This event is called "partial failure" because the detonation wave cannot jump the air gap and resume exploding the rest of the clouds. The extensive setup time and effort will be wasted if overlap does not occur.

The analysis of paragraph 4.1 proceeds from the premise that the cloud radii will be near the mean radius of a group of one-jug test shots. From a lineup of jugs of constant separation, some clouds will overlap more and some less than is intended. However, only one condition will cause partial failure. That condition is when one cloud out of the entire row has a radius that just touches its two neighbor clouds. That critically short radius constitutes a tangent cloud. The detonation wave will not enter that cloud. A drawing of the situation is seen in Figure 2.

The analysis uses statistical tables that give the probability that out of all items a proportion will exhibit a certain characteristic. In this problem, we want to have a high probability (75-99%) that nearly all (90-99%) of the clouds we would ever make will have a radius larger than the critical radius of the tangent cloud. It does not matter if the radii are bigger than the mean radius.* They all do have to be larger than the critical radius. The tables we need give the one-sided tolerance for normal distribution. First we need to derive a relation between the mean radius $\overline{R}$, the amount of overlap PR, and the jug separation S. From the geometry in Figure 2,

$$S = (2\overline{R} - P\overline{R}) = (2 - P)\overline{R} \tag{1}$$

The radius of the clouds will be a size $\overline{R}$ plus or minus some probable amount, or

$$R = \overline{R} \pm Ks, \tag{2}$$

where $\overline{R}$ is the sample mean radius and s is the sample standard deviation, and K is a constant set by probability.

Some clouds will be shorter than $\overline{R}$, like $R = \overline{R} - Ks$, and some larger, like $R = \overline{R} + Ks$, but only clouds with radius shorter than

$$R_{crit} = (1 - P)\overline{R} \tag{3}$$

will hurt JUGFAE. So the critical radius, that of a tangent cloud, is reached when

$$\overline{R} - Ks = \overline{R} - P\overline{R}$$

$$P = Ks/\overline{R} \tag{4}$$

For general interest, the proper name of the ratio of standard deviation to mean is the "coefficient of variation."

To apply Equation 4, consider these cloud radii data taken by DRES in July-August 1984. For an accurate view, an overhead camera looked down on the cloud development.**

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*In the overlap region, the fuel-air ratio is richer than in the rest of the cloud, but the wide jug spacing ensures that it is still a detonable mixture.

**Per Cecil Glass, Naval Weapons Center (NWC), China Lake, CA.

DRES jugs: volume = 53 liters
(fuel/burster)weight = 100
delay = 100 ms

$$n = 7$$

$$R_i(m) = \left| 6.55,\ 6.45,\ 6.38,\ 6.25,\ 6.10,\ 6.07,\ 5.83 \right| \text{ 7 cloud radii}$$

$$\overline{R} = \sum R_i/n = 6.233 \text{ m, sample mean radius}$$

$$s = \left[\frac{1}{n(n-1)}\left(n\sum R_i^2 - \overline{R}^2\right)\right]^{\frac{1}{2}} = 0.250 \text{ m, sample standard deviation based upon unbiased variance estimate,}$$

$$P = Ks/\overline{R} = K\ 0.250/6.233 = 0.040K, \text{ overlap required} \qquad (5)$$

We have used the s-formula for population rather than sample variability because our attention is on all clouds. Values of K are contained in tables[3] adapted from G.J. Lieberman, of which a portion is reproduced as Table 1. Table 1 gives the value of K for n shots such that we know with probability γ that a proportion of the shots P (not percent overlap now) will have a cloud radius $R > R_{crit}$. As an example, for n = 7 shots, choose a probability of 75% that 95% of all future clouds will overlap, and find in the box K = 2.250. Then with P = 0.040K, the percent overlap is 9.00%. The jug separation should be S = (2 - 0.090)6.23 m = 11.9 m.

Table 2 was drawn up from Table 1 based on two proportions, 95% and 99%, of clouds being greater than the critical radius with four probabilities of each proportion. The table shows as expected that increasing overlap is needed (closer jug separation) as probability increases. It is surprising that the most rigorous requirement, i.e., a 99% probability that 99% of clouds are larger then the critical radius, only requires 26% overlap. The overlap is low because DRES jugs reproduce the cloud radius so well. If the ratio $s/\overline{R}$ were large, as with erratic cloud sizes and small mean cloud radius, the required overlap would be large.

The peculiarities of other possible jug designs and cloud sizes do not affect the cloud overlap calculation. Another jug design could produce clouds with a different mean radius and a different standard deviation than DRES clouds. For simplicity, assume the new jugs gave the same mean cloud radius, $R_{new} = R_{DRES}$, but ranged more in size than DRES clouds. Table 3 lists what percentage overlap is required for increasingly worse standard deviations. Figure 3 plots the data listed in Table 3. As an example let the new design have three times the DRES jug's standard deviation of cloud radius, 3s = 0.75 m. If we wanted a 90% probability that 95% of these erratic clouds would be bigger than R_{crit}, the overlap required is 35%.

TABLE 1. One-Sided Tolerance Factors for Passing Proportions

Factors K such that the probability is γ that at least a proportion P of the distribution will be less than $\bar{X} + Ks$ (or greater than $\bar{X} - Ks$), where $\bar{X}$ and s are estimates of the mean and the standard deviation computed from a sample size of n.

	$\gamma = 0.75$					$\gamma = 0.90$				
n \ P	0.75	0.90	0.95	0.99	0.999	0.75	0.90	0.95	0.99	0.999
3	1.464	2.501	3.152	4.396	5.805	2.602	4.258	5.310	7.340	9.651
4	1.256	2.134	2.680	3.726	4.910	1.972	3.187	3.957	5.437	7.128
5	1.152	1.961	2.463	3.421	4.507	1.698	2.742	3.400	4.666	6.112
6	1.087	1.860	2.336	3.243	4.273	1.540	2.494	3.091	4.242	5.556
7	1.043	1.791	$\boxed{2.250}$	3.126	4.118	1.435	2.333	2.894	3.972	5.201
8	1.010	1.740	2.190	3.042	4.008	1.360	2.219	2.755	3.783	4.955
9	0.984	1.702	2.141	2.977	3.924	1.302	2.133	2.649	3.641	4.772
10	0.964	1.671	2.103	2.927	3.858	1.257	2.065	2.568	3.532	4.629
11	0.947	1.646	2.073	2.885	3.804	1.219	2.012	2.503	3.444	4.515
12	0.933	1.624	2.048	2.851	3.760	1.188	1.966	2.448	3.371	4.420
13	0.919	1.606	2.026	2.822	3.722	1.162	1.928	2.403	3.310	4.341
14	0.909	1.591	2.007	2.796	3.690	1.139	1.895	2.363	3.257	4.274
15	0.899	1.577	1.991	2.776	3.661	1.119	1.866	2.329	3.212	4.215
16	0.891	1.566	1.977	2.756	3.637	1.101	1.842	2.299	3.172	4.164
17	0.883	1.554	1.964	2.739	3.615	1.085	1.820	2.272	3.136	4.118
18	0.876	1.544	1.951	2.723	3.595	1.071	1.800	2.249	3.106	4.078
19	0.870	1.536	1.942	2.710	3.577	1.058	1.781	2.228	3.078	4.041
20	0.865	1.528	1.933	2.697	3.561	1.046	1.765	2.208	3.052	4.009
21	0.859	1.520	1.923	2.686	3.545	1.035	1.750	2.190	3.028	3.979
22	0.854	1.514	1.916	2.675	3.532	1.025	1.736	2.174	3.007	3.952
23	0.849	1.508	1.907	2.665	3.520	1.016	1.724	2.159	2.987	3.927
24	0.845	1.502	1.901	2.656	3.509	1.007	1.712	2.145	2.969	3.904
25	0.842	1.496	1.895	2.647	3.497	0.999	1.702	2.132	2.952	3.882
30	0.825	1.475	1.869	2.613	3.454	0.966	1.657	2.080	2.884	3.794
35	0.812	1.458	1.849	2.588	3.421	0.942	1.623	2.041	2.833	3.730
40	0.803	1.445	1.834	2.568	3.395	0.923	1.598	2.010	2.793	3.679
45	0.795	1.435	1.821	2.552	3.375	0.908	1.577	1.986	2.762	3.638
50	0.788	1.426	1.811	2.538	3.358	0.894	1.560	1.965	2.735	3.604

Adapted by permission from *Industrial Quality Control*, Vol. XIV, No. 10, April 1958, from article entitled "Tables for One-Sided Statistical Tolerance Limits" by G. J. Lieberman.

For a DRES jug, the percentage overlap required is only 12%. That says the DRES jugs are clearing more area, since less area is used up for overlap. In paragraph 5, we show the details of area cleared for different overlap. Actually, the area cleared decreases very slowly with increasing cloud overlap. In the last example, a line of four erratic jugs would clear only 5% less area than would the more consistent DRES jugs.

TABLE 2. Calculated Overlaps and Spacing for DRES Jugs

γ Probability of Overlap	P Proportional Number	K	(0.040K)100 Percent Overlap	$S=(2-P)\overline{R}$ Jug Spacing(m)	Jug DRES
0.75	0.95	2.25	9.0	11.9	$\overline{R} = 6.23$ m
0.90	0.95	2.89	11.6	11.7	
0.95	0.95	3.40	13.6	11.6	s = 0.250 m
0.99	0.95	4.73	18.9	11.3	n = 7
0.75	0.99	3.13	12.5	11.7	
0.90	0.99	3.97	15.9	11.5	
0.95	0.99	4.64	18.6	11.8	
0.99	0.99	6.41	25.6	10.9	

$R_{cloud} = \overline{R} \pm Ks$

A proportion of the clouds will have radius $R > \overline{R} - Ks$.

At $R = \overline{R} - Ks$, the cloud will touch its neighbors and so detonation will not propagate.

With jugs separated to give 19% $\overline{R}$ overlap, the probability is 99% that 95% of the clouds will overlap.

TABLE 3. Integer Factors of Standard Deviation of DRES Jug

$s_{DRES} = 0.250$ m $\qquad \overline{R} = 6.23$ m $\qquad P_{DRES} = (s/\overline{R})K = 0.040K$

s	γ Probability of Overlap	P Proportional Number	K	Percent Overlap Required
s_{DRES}	0.75	0.75	1.043	4.17
2s				8.34
3s				12.5
4s				16.7
s_{DRES}	0.90	0.95	2.894	11.6
2s				23.2
3s				34.7
4s				46.3
s_{DRES}	0.95	0.75	1.732	6.93
2s				13.9
3s				20.8
4s				27.7
s_{DRES}	0.95	0.90	2.755	11.0
2s				22.0
3s				33.1
4s				44.1
s_{DRES}	0.99	0.95	4.730	18.9
2s				37.8
3s				56.8
4s				75.7

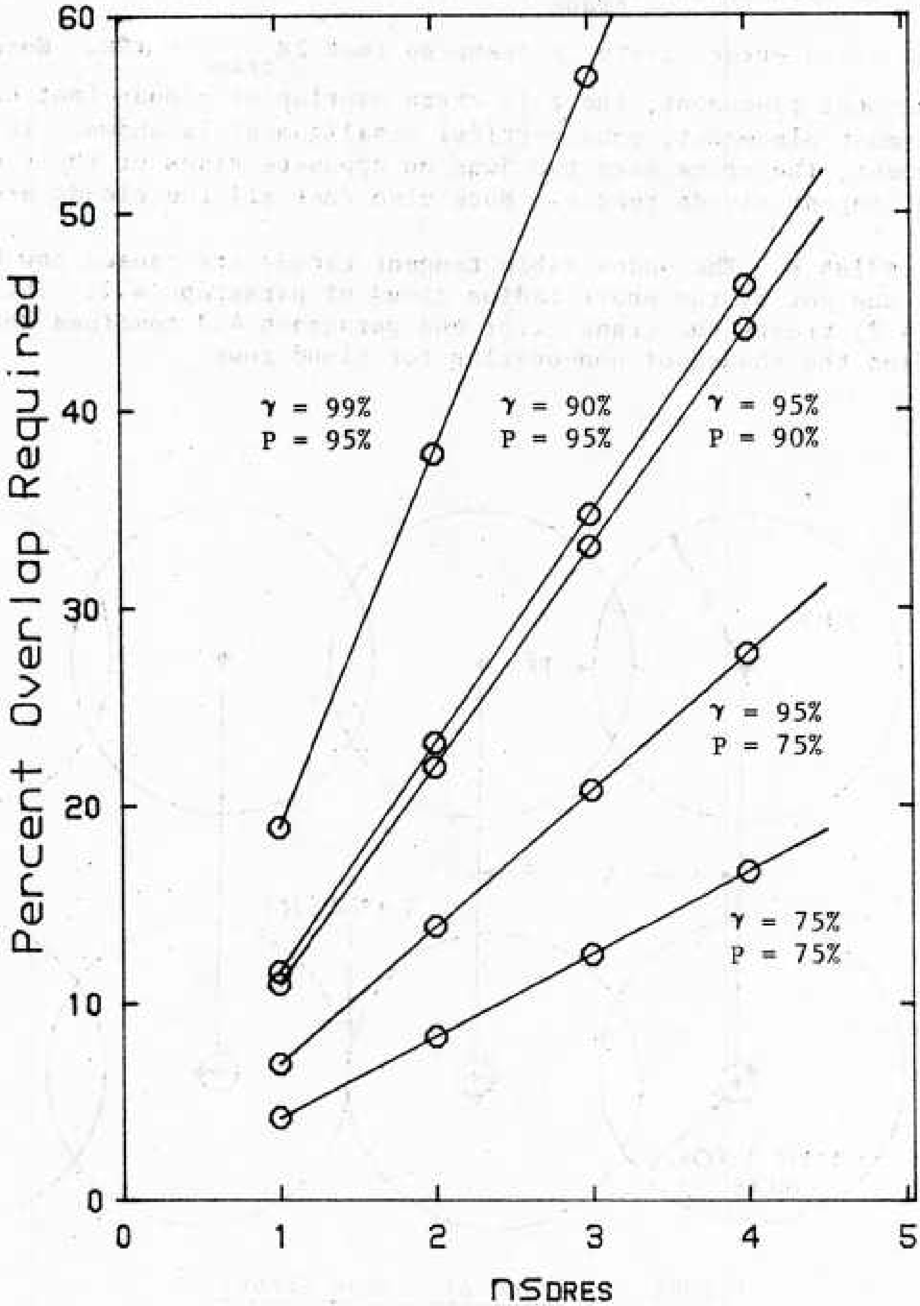


FIGURE 3. Overlap required for increasingly variable cloud radius.

4.2 Crane Placement of Jugs. The analysis in paragraph 4.1 expects perfect placement of the jugs. In the JUGFAE concept, a crane would actually set in each jug on the mined land. The crane will land the jug within some size circle of the ideal spot. This error will cause clouds to overlap different amounts. Too much error and non-overlap can occur. Figure 4 shows four-cloud arrangements from jugs perfectly placed and from jugs placed with a crane. It is assumed that the crane sets a jug down in an error circle with radius R_{crane} centered on the designated mark (+). In Figure 4 the crane error circle is drawn so that $2R_{crane} = P\overline{R}$. Note that in the right-most placement, there is extra overlap of clouds (not harmful). In the left-most placement, some vertical misalignment is shown. In the worst placement, the crane sets two jugs on opposite sides of their error circles and tangent clouds result. Note also that all the clouds are drawn with radius $\overline{R}$. The undesirable tangent clouds are caused now by crane error and not by the short radius cloud of paragraph 4.1. This paragraph (4.2) treats the crane error and paragraph 4.3 combines both errors to find the chance of non-overlap for cloud rows.

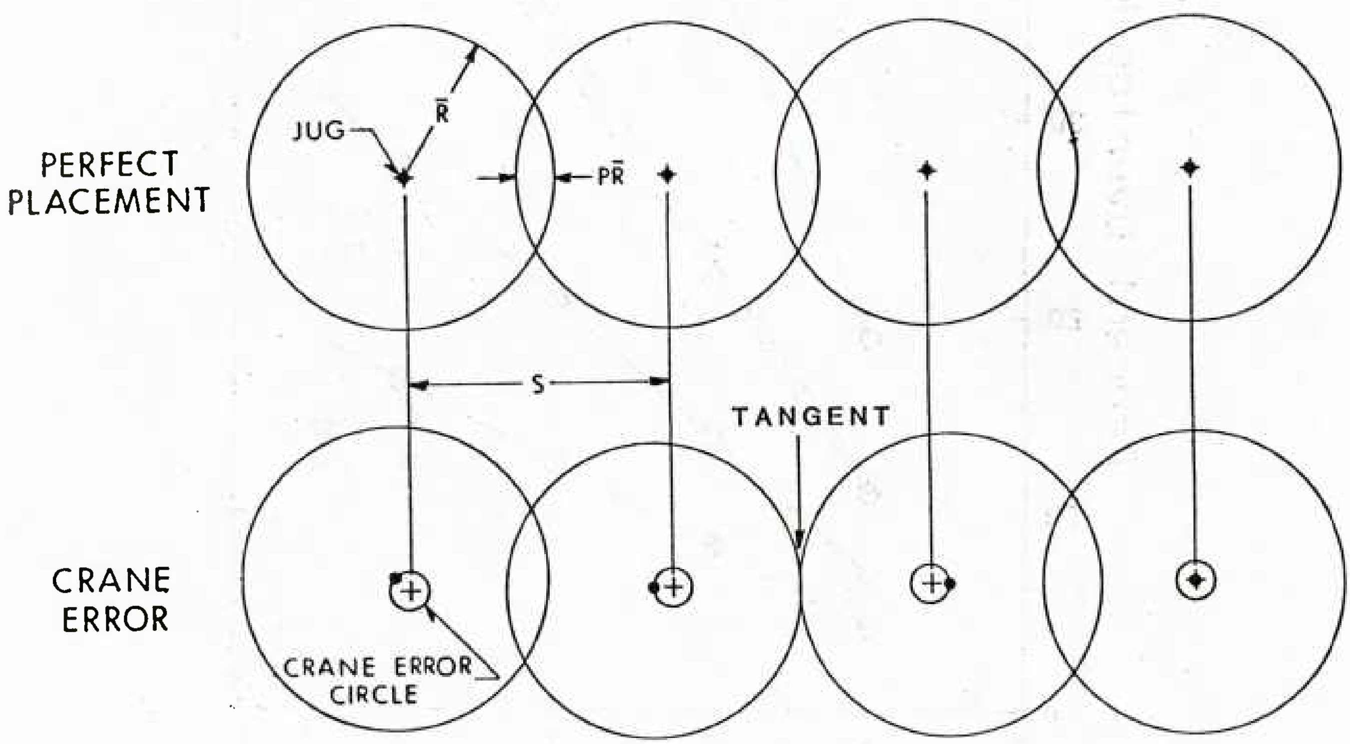


FIGURE 4. Crane placement error.

The worst case part of Figure 4 is shown in more detail in Figure 5. The top pair of clouds in Figure 5 show the jugs placed on the mark and separated a distance S. The bottom pair of clouds are tangent because the jugs are on opposite sides of the crane's error circle. To ensure detonation transfer in the worst case, the jugs must be put on a closer separation S',

$$S = 2\bar{R} - P\bar{R} \tag{6}$$

$$S' = S - 2R_{crane} \tag{7}$$

$$R_{crane} = 2\sigma_{crane} < P\bar{R}/2 \tag{8}$$

where the equality is for statistical reasons from Reference 4 and the inequality is error we are willing to tolerate or must expect from crane emplacement. σ_{crane} is the standard deviation of the miss distance of the jug from the mark. Collecting terms,

$$S' = (2\bar{R} - P\bar{R}) - 2P\bar{R}/2 \tag{9}$$

$$S' = 2\bar{R}(1 - P) < S \tag{10}$$

If jugs are set S' apart, then if the worst placement does happen, the clouds would still overlap.

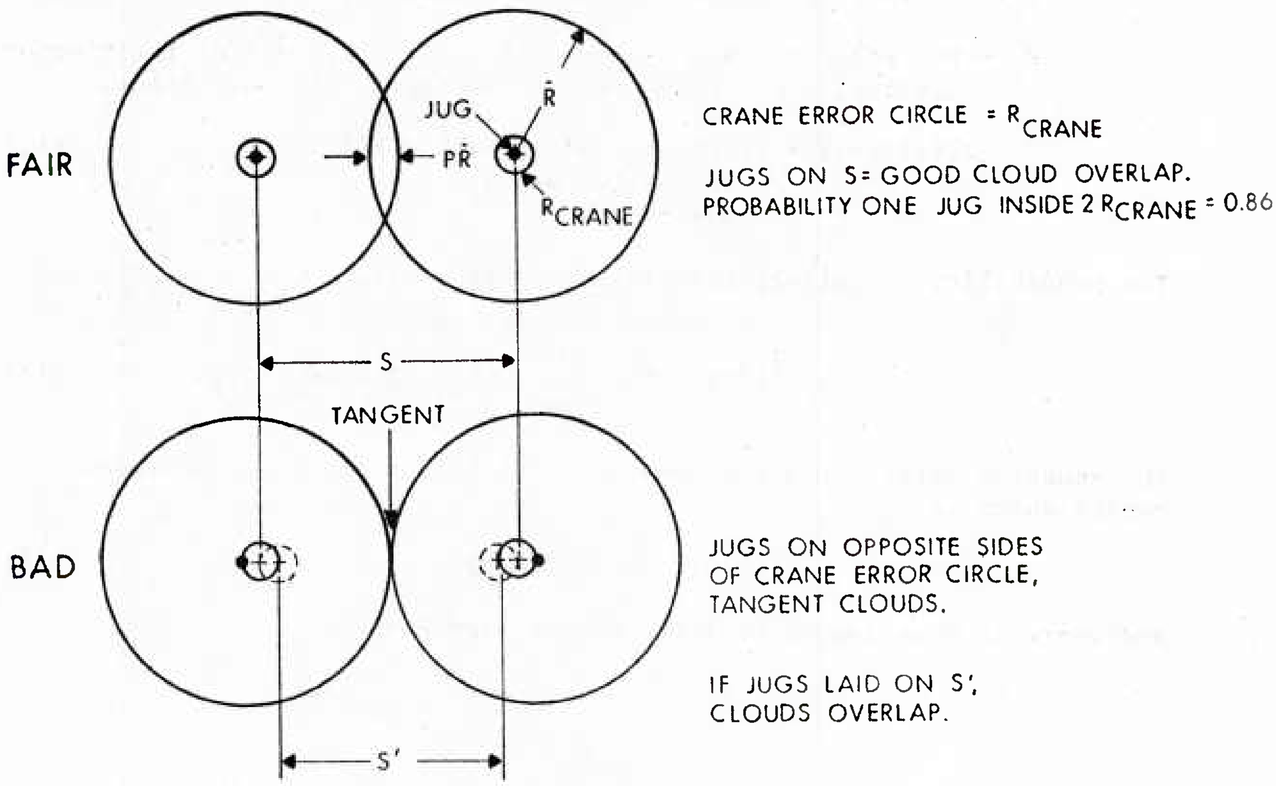


FIGURE 5. Worst crane placement.

From Equations 6-8, if the chosen overlap is P = 25%, then $S = 1.75\overline{R}$, $S' = 1.50\overline{R}$ and $R_{crane} = 0.25(6.23)/2 = 0.78$ m. These results show a reasonable compromise between keeping jug separation large and restricting the crane error. Since $S' < S$, there will be less area cleared or more jugs needed if the jugs are placed on marks separated by S'. The reduction in area cleared per setup is about 9% from paragraph 5.1 or an increase of 11% in the number of jugs is needed.

At this point, the problem of predicting JUGFAE success, with the necessary crane placement included, is solved in a limited way. With all jugs placed on the S'-separation, detonation transfer is assured. If we wish to keep the jugs on the wider S-separation, then the probability calculation is much harder. The reader may wish to skip the details as paragraph 4.3 concludes that the S'-separation should be used in JUGFAE operations if not any risk of partial detonation of the line is acceptable. The rest of this section and paragraph 4.3 detail the risks for multiple jug lineups.

For failure to detonate the entire cloud line, three events must have occurred in jug placement, as shown in Figure 5.

E_0 = The crane puts i jugs outside its permitted error circle.

E_1 = At least 2 outside jugs are adjacent.

E_2 = The adjacent jugs are on left and right sides of their error circles, i.e., they are too far apart from each other.

$$P(\text{failure}) = P(\text{failure to transmit detonation w/crane placement}) = P(E_2 \cdot E_1 \cdot E_0) \quad (11)$$

The probability of failure P(failure) can be written

$$P(\text{failure}) = \sum_{i=0}^{n} P(E_0)_i \; P(E_2 \cdot E_1 | E_0)_i \quad (12)$$

The equation arises from the compound probability law for independent events which is

$$P(A \cdot B) = P(B)\; P(A|B), \quad (13)$$

and where in Equation 13 we let $A = E_2 \cdot E_1$ and $B = E_0$.

The summation comes from the probability rule that separate probabilities of mutually exclusive outcomes are added to give the total probability, if we do not care which outcome occurred (the "or" rule). In this application, we do not care if failure occurred because the crane mislaid no jug or one jug, or...., and so we add the probability of each separate jug line occurring.

We solve Equation 12 for the example of a 2-jug lineup. The result is the probability of failure with two jugs or the probability that the particular arrangement of Figure 5 BAD will occur. The solution uses a diagrammatic method of Robert L. Umholtz of BRL.

The condition that a jug is inside the crane error circle R_{crane} is signified with a cross (+) because being inside is as good as being right on the mark (+). The condition that a jug is on or outside the error circle is signified with a zero (0).

The number of arrangements of n jugs with r of them being on or outside the crane error circle is given by $\binom{n}{r}$ in the usual notation and written here C(n,r),

$$\binom{n}{r} = C(n,r) = n!/r!(n-r)! \qquad (14)$$

With n = 2 jugs, r can be 0, 1, or 2 meaning no jugs outside, one jug outside, both jugs outside the crane error circle.

All the possible arrangements of two jugs look like:

None Outside	One Outside	Two Outside
C(2,0) = 1	C(2,1) = 2	C(2,2) = 1
+ +	+ 0 0 +	0 0

This diagram is incomplete for finding probability of failure with crane placement because only event E_1 is depicted. The event E_2 is depicted by writing left L or right R under each 0. With more jugs, it is useful to know that the number of sub-pictures is 2^r.

2-Jug Arrangements

None Outside			One Outside				Two Outside		
C(2,0)=1	+	+	C(2,1)=2	+ 0	0 +		C(2,2)=1	0	0
2^0=1	+	+	2^1=2	+ L	L +		2^2=4	L	L
				+ R	R +			L	R*
		0/1		0/2	0/2			R	L
								L	L
									1/4

The asterisk above marks the only occurrence of failure, abbreviated $E_2 \cdot E_1 \cdot E_0$, and in fact is the "BAD" of Figure 5. The fractions give the probability of failure for that exact lineup of jugs. In practical terms, if the project officer in some way detected that one jug was outside the crane error circle, he would know from the diagram that the probability of failure was zero, $(0/2 + 0/2)/2 = 0$; he would not even have to know which jug in particular was mislaid. On the other hand, learning that both jugs are outside the crane error circle, he then knows the chance of failure is 1/4 if he elects not to correct one setting (either one) but goes ahead and fires. If the project officer knows nothing about the setting of the jugs, the probability of failure is the *a priori* probability calculated by Equation 12.

The second term in Equation 12 is $P(E_2 \cdot E_1 \cdot E_0)_i$ and is read off the diagram. The first term, $P(E_0)_i$, is obtained from the binomial distribution, which gives the probability of getting r events in n tries when the probability of getting a single event is p.

$$P(E_0)_i = C(n,r)p^r(1-p)^{n-r}, \quad i = 0,1,\ldots n \tag{15}$$

The number C(n,r) is Equation 14. The important probability of the crane mislaying one jug is $p = (1 - 0.865) = 0.135$, by way of Reference 4 and the definition of R_{crane} in Equation 8.

So the probability of the crane mislaying r jugs is:

$$P(E_0)_0 = P(0 \text{ outside}) = C(2,0)p^0(1-p)^{2-0} = 1(0.135)^0(0.865)^2 = 0.7482 \tag{16}$$

$$P(E_0)_1 = P(1 \text{ outside}) = C(2,1)p^1(1-p)^{2-1} = 2(0.135)^1(0.865)^1 = 0.2336$$

$$P(E_0)_2 = P(2 \text{ outside}) = C(2,2)p^2(1-p)^{2-2} = 1(0.135)^2(0.865)^0 = 0.0182.$$

Equation 12 stated for the 2-jug lineup is:

P(failure) = (prob. crane mislays 0 jugs)(prob. at least 2 jugs are adjacent & opposite given that 0 are mislaid) (17)
+ (prob. crane mislays 1 jug)(prob. at least 2 jugs are adjacent & opposite given 1 is mislaid)
+ (prob. crane mislays 2 jugs)(prob. at least 2 jugs are adjacent & opposite given that 2 are mislaid)

$$P(\text{failure}) = 0.7482(0) + 0.2336(0) + 0.0182(1/4),$$

$$P(\text{failure}) = 0.00455.$$

The method of the 2-jug example can be extended for more jugs, but the details are inappropriate for a concepts report. Some interesting mathematics occur and will be displayed in a future report. Table 4 summarizes results of crane placement error for several jug lines.

TABLE 4. Probability of Partial Failure With Crane Placement of Jugs.

Number of Jugs in Line	Probability That Crane Placement on S-Separation Will Cause At Least One Tangent Cloud
2	0.00455
3	0.00911
4	0.0139
5	0.01815
10	0.0399

Crane error permitted is $P\overline{R}/2$ or half the cloud overlap distance.

4.3 Tangent Cloud and Crane Error Combined. A partial failure to detonate a row of clouds will arise from crane error or the critical short cloud occurring. Call the latter event E_3. From paragraph 4.1, the probability of a critically short cloud forming is very low for an intended percentage overlap of P = 15% or more. So $P_n(E_3) = 0.010$. The probability of either error occurring is

$$P(E_3 \text{ or } E_2 \cdot E_1 \cdot E_0) = P(E_3) + P(E_2 \cdot E_1 \cdot E_0) - P(E_3 \cdot (E_2 \cdot E_1 \cdot E_0)) \quad (18)$$

The last term on the right is the chance that both errors have occurred to at least one pair of jugs. We cannot evaluate the term but it may be very small, so call it zero. Even if it is not zero, the assumption gives an upper bound on P(either error). Then, applying Equation 18 to two jugs,

$$P_2(\text{either error}) < 0.010 + 0.0046 - 0.00 = 0.015 \quad (19)$$

The example for two jugs has been applied to cases of longer rows and the results are compiled in Tables 5 and 6.

TABLE 5. Probability of Partial Failure With S-Separation of Jugs

Jugs	$P(E_2 \cdot E_1 \cdot E_0)^{+}$	$P(E_3)^{++}$	$P(E_3 \text{ or } E_2 \cdot E_1 \cdot E_0)^{\#}$
2	0.0046	< 0.010	< 0.015
3	0.0091	< 0.010	< 0.019
4	0.0139	< 0.010	< 0.024
5	0.0182	< 0.010	< 0.028
10	0.0399	< 0.010	< 0.050

\+ Chance of crane error causing partial detonation in row.
++ Chance of critical short cloud causing partial detonation in row.
\# Chance of crane error or critical short cloud causing partial detonation in row.

Rows of 10 jugs may be a reasonable line to set up. The (not large) probability of partial failure with a 10-jug row makes a problem because a great many jugs, say 100, have to be fired every day in order to clear large areas in a time like one year (paragraph 5.4). The binomial distribution (Equation 15) gives the probability of getting exactly r incomplete detonation among the n setups scheduled each day.

$$P(r) = C(n,r)p^{r}(1-p)^{n-r}, \tag{20}$$

where p is the last column of Table 5 or the probability of a single setup failing. For no incomplete detonations, r = 0 and the probability of success is simply

$$P(0) = (1-p)^{n}. \tag{21}$$

The complement of this number P(0) has to be the probability of at least one incomplete detonation, $P(r \geq 1) = 1 - P(r = 0)$ or

$$P\ (r \geq 1) = 1 - (1-p)^{n}. \tag{22}$$

As an example of the use of these equations, consider a 5-jug line which is setup 20 times. Equation 21 and Table 5 give the chance of no failures,

$$P(0) = (1 - 0.028)^{20} = 0.567.$$

Equation 20 gives the chance of exactly one failure as

$$P(1) = C(20,1)(0.028)^{1}(1 - 0.028)^{20-1} = 0.326.$$

Equation 22 gives the chance of at least one failure as

$$P(1 \text{ or more}) = 1 - (1 - 0.028)^{20} = 0.433.$$

Table 5 and Equations 21, 20, and 22 give Table 6 in which rows of N jugs are fired repeatedly. The probability of partial failure decreases in the long rows even though the number of jugs is constant at Nn = 100.

TABLE 6. Probability of at Least One Partial Failure in n Setups

N Jugs in Row	n Setups	No Failures	Exactly One Partial Failure	One or More Partial Failures
2	50	0.470	0.358	0.530
3	33	0.531	0.339	0.469
4	25	0.558	0.335	0.455
5	20	0.567	0.326	0.433
10	10	0.599	0.315	0.401

The probability of partial failure can be reduced greatly by two techniques: put the jugs on separation S' and put out two rows in each setup (see Figure 9). About 11% more jugs are needed for the S'-mark than the wider S-mark. Two rows may be difficult to put in. The ideal operation has for the jugs themselves that the cloud radius is large and reproducible so that $s/\overline{R}$ is very small and the crane error $R_{crane} = 2\sigma_{crane}$ is very small. The sections ahead are concerned with area cleared and not probability of cloud detonation. The jugs are assumed to be on the wider S-separation. For exploratory tests where the jugs are hand emplaced, the S-mark would be used; for operational tests where the crane is essential, the S'-mark could be used or a jug separation which reasonably secures cloud overlap, e.g., $1.75\overline{R}$, could be used.

5. AREA COVERAGE

5.1 Graphical Solution. The area under the clouds must decrease as the overlap increases. The lost area is minor, however, even at high overlaps. Figure 6 shows four circles at overlaps ranging from 15% to total, i.e., nearly tangent clouds to superimposed clouds. The circumscribed areas were measured with a planimeter and the result is shown as a plot of area vs percent overlap. At 0% overlap, the area is 303 vernier units and at 40% overlap the area declines only to 282 vernier units. The 40% overlapped area is 95% of the area from tangent clouds

(282/303), which we argued is the failure size. The tradeoff of more overlap, ensuring detonation transfer, for slightly decreased ground coverage is very favorable. The 25% overlap is a good choice.

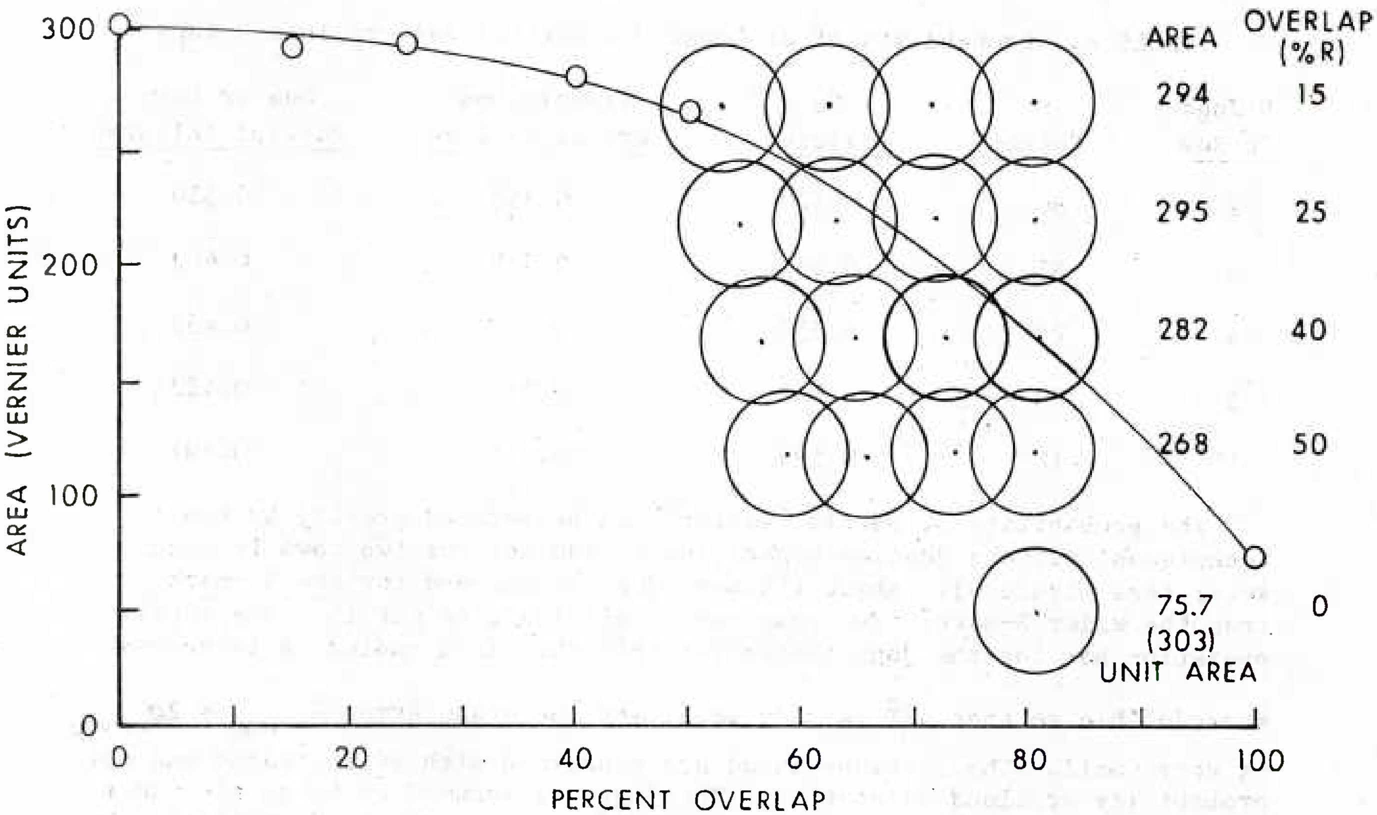


FIGURE 6. Measured area for different overlaps.

5.2 Exact Solution. To find an exact expression for the total area A_n of n overlapped clouds, we need the area of the overlap. For n clouds, there are (n - 1) overlap areas so the total area may be written,

$$A_n = nA - (n - 1)A_{overlap} \tag{23}$$

and $A = \pi R^2$ is the area of one cloud.

The problem is to find the area of overlap (the area of the vesica piscis). A geometry solution due to J. Richard Moore, a BRL retiree, will be given and confirmed by a calculus solution.

Let a circle of radius R represent a cloud of average radius $\overline{R}$. The overlap portion of two circles is shown in Figure 7A as arcs 23472. With geometry, (half) the overlap area is found by subtracting the area of the large triangle, 1241, from the area of the sector 12341. With the circles separated by S, length 15 is S/2 and length 52 is

$$\sqrt{R^2 - S^2/4} \text{ by Pythagoras.}$$

$$A_{1241} = 1/2\ (\text{base})(\text{height}) \qquad (24)$$

$$A_{1241} = S/2\ \sqrt{R^2 - S^2/4}$$

The sector area is a fraction of the circular area πR^2.

$$A_{12341} = (\pi R^2)(\theta/2\pi) \qquad (25)$$

$$\cos(\theta/2) = S/2R \text{ or } \theta = 2\arccos(S/2R)$$

$$A_{12341} = R^2/2(2\arccos(S/2R))$$

Overlap area is

$$A_{23472} = 2(A_{12341} - A_{1241}) \qquad (26)$$

$$A_{overlap} = 2R^2\arccos(S/2R) - S\sqrt{R^2 - S^2/4} \qquad (27)$$

Also since

$$\sin(\theta/2) = \sqrt{R^2 - S^2/4}\Big/R$$

$$A_{overlap} = 2R^2\arcsin\left[\sqrt{R^2 - S^2/4}\Big/R\right] - S\sqrt{R^2 - S^2/4}. \qquad (28)$$

The exact solution by calculus for the overlap area consists of double integration over a quarter of the vesica piscis. An origin of xy coordinates placed at point 6 in Figure 7A is redrawn for the calculus solution of Figure 7B. The integral is

$$A_{overlap} = 4\int_0^x dx \int_{S/2}^y dy \qquad (29)$$

where

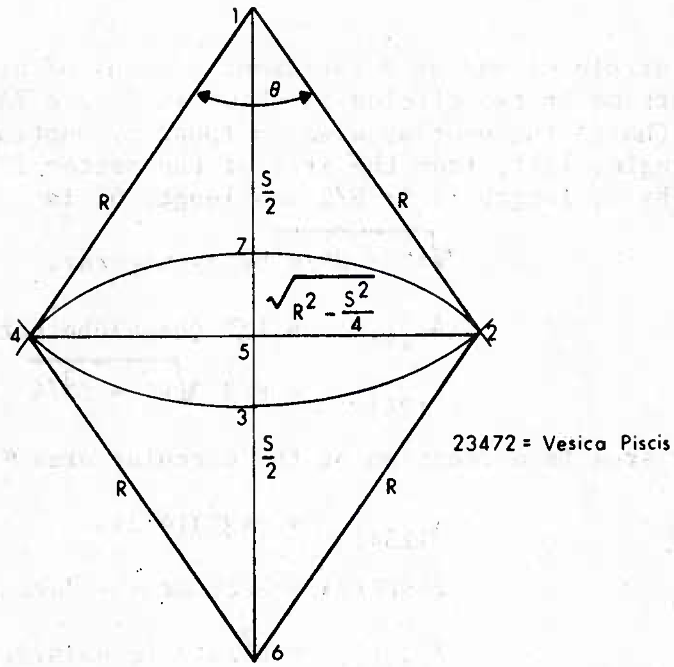
$$x = \sqrt{R^2 - S^2/4} \text{ and } y = \sqrt{R^2 - x^2}$$

$$A_{overlap} = 4\int_0^x (y - S/2)dx \qquad (30)$$

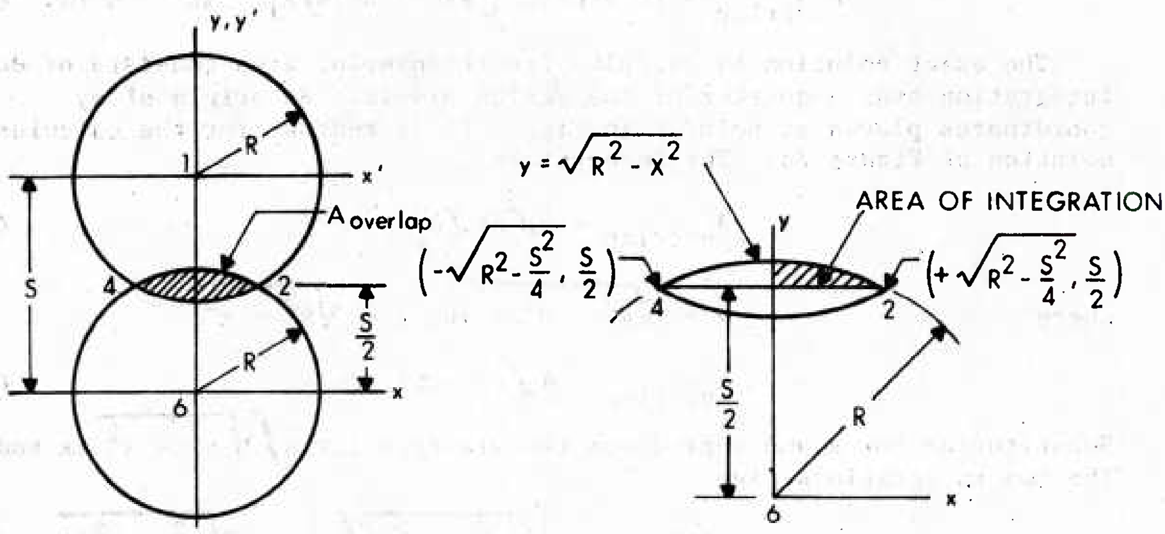
Substitution for x and y produces the standard forms $\int\sqrt{a^2 - x^2}\,dx$ and $\int dx$. The two integrations give

$$A_{overlap} = 2R^2\arcsin\left[\sqrt{R^2 - S^2/4}\Big/R\right] - S\sqrt{R^2 - S^2/4}. \qquad (31)$$

Equation 31 is also 28, so the methods agree.



(A) Geometry Solution



(B) Calculus Solution

FIGURE 7. Calculated overlap area.

A change of variables found by Robert L. Umholtz of BRL expresses Equation 28/31 more simply. Regard the area of overlap to be the sum of two terms which we shall call A_1 and A_2,

$$A_{overlap} = A_1 + A_2 \tag{32}$$

The simplifying substitution is $v = S/R$ (v for vesica piscis), which is the ratio of the jug separation to the cloud radius. Operate on the term A_1 of Equation 32 and 28/31 by bringing R inside the radical, dividing through, and substituting v.

$$\begin{aligned} A_1 &= 2R^2 \arcsin\left[(R^2 - S^2/4)/R^2\right]^{\frac{1}{2}} \\ &= 2R^2 \arcsin\left[1 - (v/2)^2\right]^{\frac{1}{2}}. \end{aligned}$$

After some algebra and the trigonometric identity $\sin^2\theta + \cos^2\theta = 1$ obtain,

$$A_1 = 2R^2 \arccos(v/2). \tag{33}$$

Proceeding with A_2,

$$\begin{aligned} -A_2 &= S\left[(R^2 - S^2/4)\right]^{\frac{1}{2}} \\ &= R^2 v \left[1 - (v/2)^2\right]^{\frac{1}{2}} \end{aligned} \tag{34}$$

$$A_{overlap} = A_1 + A_2, \quad 0 \leq v \leq 2, \quad v = S/R. \tag{35}$$

If we wanted to compare $A_{overlap}$ to $A_{circle} = \pi R^2$, this ratio would be

$$A_{overlap}/A_{circle} = \frac{1}{\pi}\left[2\arccos(v/2) - v\sqrt{1 - (v/2)^2}\right], \tag{36}$$

which only depends on v.

5.3 Multiple Rows. A JUGFAE setup is flexible and not restricted to a single line. Spotting the jug marks for the crane is a problem that must be worked out. Cord marked for the jug separation and a cord tied on the crane hook to get the same depth into the minefield might work.

For moderate sized setups it is useful to have area formulas other than the exact formula and the very large scale formulas of the next section. Generalizing from Figure 2, the length L can be written two ways:

$$L = R + (n - 1)S + R = nD - (n - 1)L_{overlap} \tag{37}$$

Recalling that $S = 2R - PR$ and $L_{overlap} = PR$, these expressions can be shown to be identical. In forming the next row, better ground coverage will result if the jugs are overshifted onto the perpendicular bisectors of the jug spacing of the front row. The jug centers lie on equilateral triangles of side S and the depth W of the two cloud rows can be written:

$$W = R + S\sqrt{3}/2 + R. \tag{38}$$

Lining up the jug centers in each row leaves too much open ground. This statement can be checked by playing with rows of pennies. Figure 8 shows that the open area of multiple rows, as in Figure 9, can be entirely eliminated if the jug spacing is related to the cloud radius by S = 1.73R. The overlap in Figure 8 is 0.27R or very close to the 0.25R favorably mentioned in paragraph 5.1.

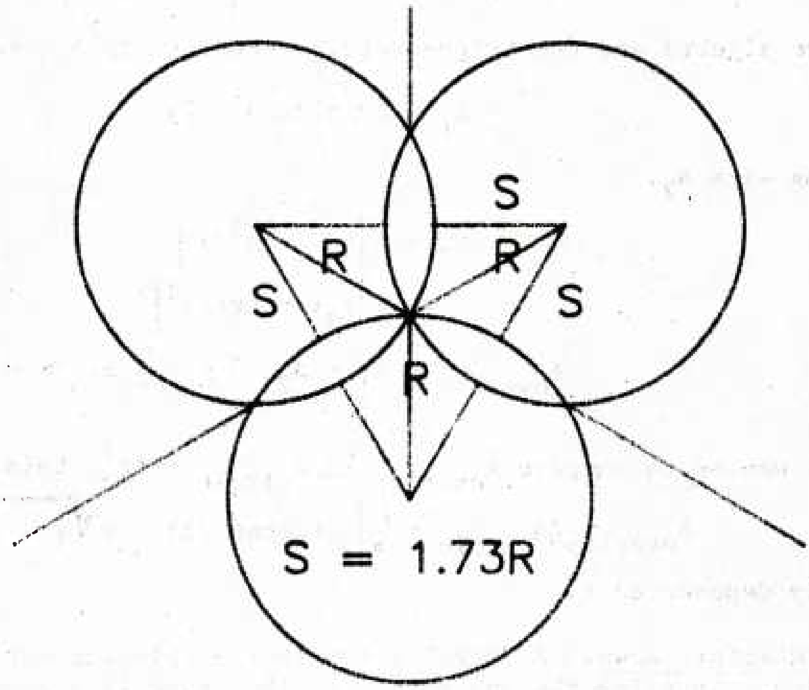
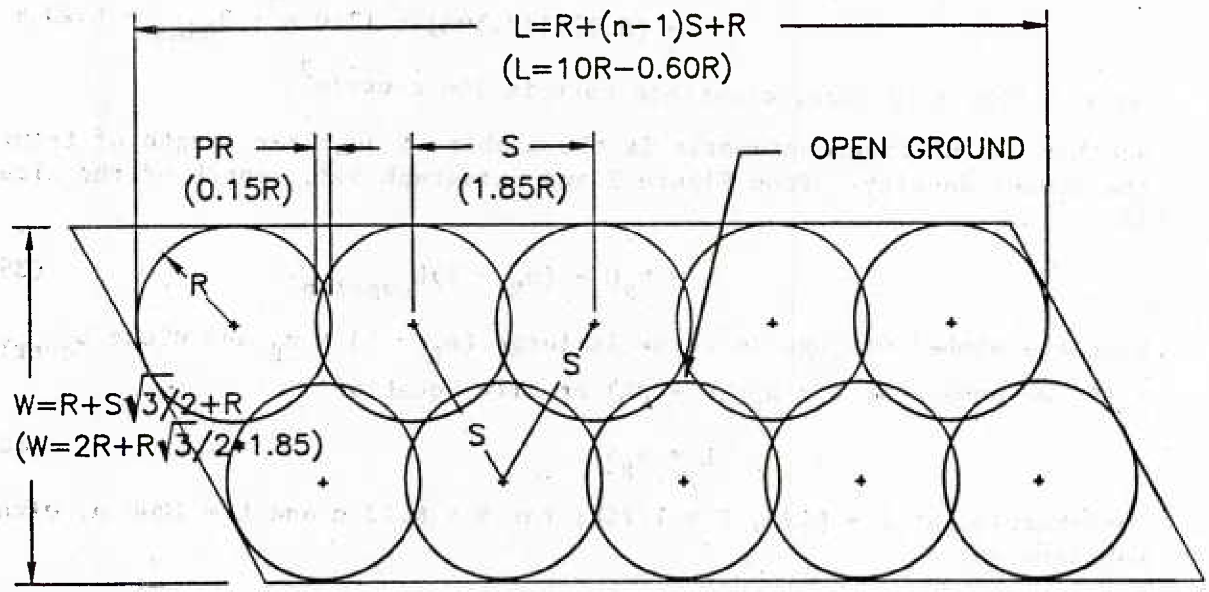


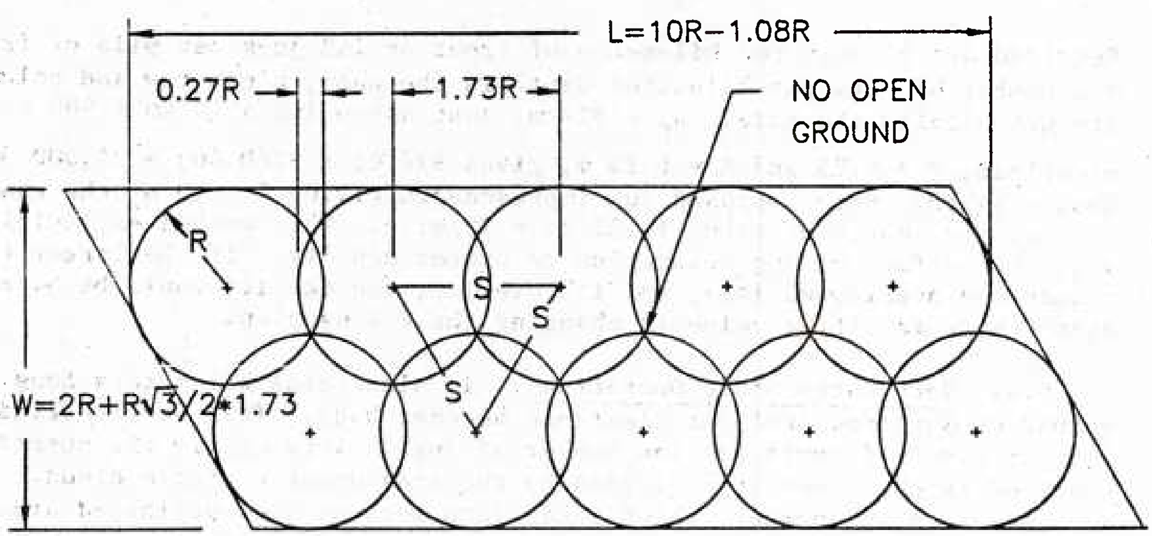
FIGURE 8. Jug spacing that leaves no open ground.

Figure 9 shows multiple rows specialized as two rows of 5 jugs with an overshift (2 x 5 shift) and 15% overlap (9A) and 27% overlap (9B). The area covered is nearly that of the confining parallelogram.

$A_{parallel}$ = LW, the length by the depth of the parallelogram, where the cloud length (Equation 37) will serve as the slightly longer parallelogram length and the depth is given by Equation 38.



(A) 15% Overlap leaves open ground.



(B) 27% Overlap leaves no open ground.

FIGURE 9. Multiple rows.

For a 2x5 shift and 15% overlap, the area covered is:

$$A_{parallel} = (10R - 0.60R)(2R + R\sqrt{3}/2*1.85)$$

$$= (9.40R)(3.60R) = 1320 \text{ m}^2;\ R_{DRES} = 6.23 \text{ m}.$$

For a 2x5 shift and 27% overlap, the area covered is:

$$A_{parallel} = (10R - 4(.27)R)(2R + R\sqrt{3}/2*1.73)$$

$$= (8.92R)(3.50R) = 1210 \text{ m}^2;\ R_{DRES} = 6.23 \text{ m}.$$

At \$134/jug x 10 jugs, clearance cost is 106 cents/m^2.

Another useful figure-of-merit is the number of jugs per length of front, the number density. From Figure 2 and paragraph 5.3, length of the clouds is

$$L = n_R D - (n_R - 1)L_{overlap}. \qquad (39)$$

When the number of jugs in a row is large $(n_R - 1) \simeq n_R$ and since $L_{overlap} = PR$, we have that $L = n_R(2R - PR)$ or with Equation 1

$$L = n_R S. \qquad (40)$$

For example, at P = 0.25, S = 1.75R; for R = 6.23 m and L = 1000 m; with Equation 40:

$$1000 \text{ m} = n_R(1.75)(6.23 \text{ m})$$

$$n_R = 92/\text{km}.$$

Required are 92 jugs per kilometer of front or 148 jugs per mile of front. The number of jugs per kilometer depth is the same, since row and column are graphically the same. $n_C = 92/\text{km}$. Just supposing a 10 km x 400 m minefield, P = 0.25 and R = 6.23 m, gives 92(10) x 92(0.40) = 34,000 jugs; Cost = \$4.5M. With supposed jug improvements giving R = 10 m, the number of jugs per length of front is 57/km = 92/mile. This method explicitly shows the effect of jug separation on number density. If the larger (10 m) clouds are overlapped less, say 15% overlap, the density would be 54/km. Again there is little value in changing the 25% overlap.

5.4. Very Large Scale Operations. In minefields kilometers long the number of jugs required for clearance becomes huge. This section finds another simple formula for the number of jugs. Very nearly the number required is the mined area divided by the area under a single cloud. A correction to the number, which takes into account the overlapped area, can be found. The ratio of the exact area covered by n jugs, A_n, to n times the area covered by a single jug A is changeable and less than one. However, as we shall show, the ratio reaches a limit as $n \rightarrow \infty$, which is about 0.95. Using Equation 23 and calling $A_o = A_{overlap}$,

$$\lim_{n\to\infty} \frac{A_n}{nA} = \lim_{n\to\infty} \frac{nA - (n-1)A_o}{nA} = \frac{\infty}{\infty}$$

The limit can be found by separately differentiating the numerator and denominator, l'Hopital's rule.

$$\lim_{n\to\infty} \frac{A_n}{nA} = 1 - \frac{A_o}{A} \frac{\lim_{n\to\infty} \frac{d}{dn}(n-1)}{\lim_{n\to\infty} \frac{d}{dn}(n)}$$

$$\lim_{n\to\infty} \frac{A_n}{nA} = 1 - \frac{A_o}{A} \tag{41}$$

where the overlap area is given by Equation 28/31.

To apply the limit, suppose the jugs are on a 25% overlap, P = 0.25R, which makes the jug separation S = 1.75R. Refer to Equation 36 with v = 1.75 for $A_{overlap} / A_{circle}$, which we have called A_o/A in Equation 41.

$$A_o/A = \frac{1}{\pi} \left[2\arccos(1.75/2) - 1.75\sqrt{1 - (1.75/2)^2} \right] = 0.0525.$$

Graphically, Figure 6, the ratio measured is 1 - 0.974 = 0.026, which is smaller than 0.0525 because the area overlapped by four jugs has to be less than the area overlapped as $n \to \infty$.

$$\lim_{n\to\infty} \frac{A_n}{nA} = 1 - \frac{A_o}{A} = 1 - 0.0525 = 0.9475. \tag{42}$$

This exercise shows that a limit exists between exact area and n-tuple area of clouds. Furthermore, the cumulative overlap area (for jugs on 1.75R separation) is small, in agreement with other sections. Rather than calculate the area from the function for A_n in Equations 23 and 28, one can simply take the area from one jug and multiply by the number of jugs. The error is only 5%, which is enough accuracy for operations planning.

$$A_n = 0.95\ nA \simeq nA. \tag{43}$$

To find the number of jugs needed to neutralize a minefield of area A_m, set it equal to the area from all the clouds A_n (Equation 43).

$$A_m = A_n, \text{ clearance requirement}$$

$$n = A_m/0.95A. \tag{44}$$

Return to the possible large minefield of 10 km x 400 m, length by depth. $A = A_{jug} = \pi R^2 = \pi(6.23\ m)^2 = 122\ m^2$ for the DRES jug. n = 34,500 jugs. Cost = \$4.62 M or \$1.16/m^2. Note that this example was worked by the number density method, Equation 40, which gave n = 34,000 jugs, a 2% difference.

The 34,000 jugs needed for the large minefield dictates a crowded firing schedule in order to finish in a reasonable time. One hundred jugs a day would complete it in 340 days or 1 year. Possibly, a smoothly operating range party could fire 100 jugs a day. If so, two teams, a non-interfering distance apart, could halve the time to six months. The cost estimate of paragraph 2.3 listed a 6-man team at \$360K/year. Neither the personnel cost nor the fixed equipment cost (\$79K) are included in the cost of one dollar for expendables for a square meter cleared.

6. CONCLUSION

The JUGFAE concept has been described in detail. The central idea of JUGFAE is the simultaneous dispersion of fuel into overlapping fuel-air clouds and one subsequent mine clearing explosion. We think it is the best means for blast clearance of land mines, where the approach taken is total clearance without regard for detection. Mechanical means such as plows and rollers also are part of the no-regard-for-detection approach.

The alternative approach is individual detection of each land mine. It is outside the scope of this report to compare approaches or means, but they should be kept in mind.

The jugs have been described in detail sufficient to understand that they are inexpensive and easily manufactured. The setup operation has been explained as has the necessity for the multiple jug setup with its advantages of control and safety and timesaving over one-at-a-time firing. Considerable detail makes clear that placement errors in the jug setup are small enough to give high probability that the clouds will overlap. That overlap is necessary for the detonation wave to travel throughout the array. The array is whatever geometrical design the user prefers or terrain or crane reach dictates. The number of jugs required for any area was found. With a 6.23 m cloud radius and for long minefields the number of jugs is 92 per kilometer of front. The clearance cost in expendables (not counting the crane) is about one dollar per square meter.

The feasibility of operations at very large scale was briefly examined. In very large minefields, the number of jugs needed is in the tens of thousands. The concept may be impractical at that scale as time, men, and money needed are large.

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